CALIBRATION LABORATORY

Automatic Pressure Calibration System

National Aeronautics and Space Administration
Glenn Research Center - Calibration Laboratory
Cleveland, Ohio 44135

SIGNATURE PAGE

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1. SCOPE

The function of this automatic system is the following:

A. To provide calibration for pressure transducers

B. To evaluate newly purchased transducers and to insure that they meet manufacturer specifications

C. To generate data to allow statistical evaluation of the transducers.

2. GENERAL OVERVIEW

This document is a request for a quote to provide a fully integrated, automatic pressure calibration system to the Glenn Research Center. This document details the requirements for the procurement of an automatic pressure calibration system. The automatic pressure system needs to be able to calibrate 10 pressure transducers, concurrently, ranging from 1 PSI up to 3000 PSI. All type of pressure transducers (differential, gauge, absolute, or bidirectional gauges) need to be calibrated with the system. The minimum range for absolute pressure transducer is 15 PSI. The reference for the absolute pressure could be chosen by technician to be 100 mTorr or 200 mTorr, and it should be controlled to the chosen value. The system is to be capable of properly calibrating pressure transducers that have voltage and 4 to 20 mA outputs. The new automatic pressure system shall provide calibrations fully compliant with ANSI/Z540.3 -2006 Requirements for Calibration of Measuring and Test Equipment (this includes measurement uncertainties and customer risk calculations)

This system must comply with ANSI/NCSL Z540.3. Z540.3 requires reporting measurement uncertainty (MUA) for each point taken, measurement uncertainty to be documented and conformance criteria to comply with the two percent decision rule (see Z540.3 for requirements). The software delivered with this new system SHALL meet Z540.3 requirements, AND shall include MUA, guardbanding and pass/fail determination for the 2 percent false accept rule.

The offeror of this system shall provide setup, to include mechanical and electrical assembly to provide a completed, functional system at Glenn, as necessary to insure the integrity of the hardware and calibration process. Operator training shall be provided to allow immediate use of the system, and documentation shall be provided for use and maintenance of the system.

2.1. <u>Hardware</u>

The accuracy requirements for the pressure controller needs to be the best available from the vendor (see specifications from the table below). All the supporting components listed below will be integrated into a cabinet or equipment rack. The cabinet will have fans to avoid excessive internal heat build-up. All components need to be easily accessible through cabinet doors. There shall be easy access to all pressure heads from the outside cabinet for the purpose of calibration. All heads shall be isolated for the purpose of calibration.

The system shall have two (2) pressure ports used for all testing. One port shall be the low or reference side and the other shall be the high side. The system shall be supplied to allow electrical and mechanical connections made to the unit(s) under test, and ancillary data related to each calibration event entered into the system (to include the range, transducer type, output type, data reduction method, transducer information, etc.). No interaction by the technician shall be required until the calibration is complete. At that point, the system should prompt the tech that the calibration is complete and is ready for report printing. The two ports shall be made of AN fittings.

The system requires an external single pressure supply of gaseous nitrogen (supplied by NASA) and a single AC power source. During each calibration the effect of temperature, overpressure, pressure cycling, and reference pressure (on differential transducers) can be measured, collected and addressed as necessary to perform the calibration. All hardware should use industry-standard bus types (i.e. Serial, IEEE-488, USB, etc) for instrument communication and control.

The Glenn Calibration Laboratory shall provide the necessary vacuum pump(s) and the digital multimeter for the system. The provided system shall control the vacuum level at 100 mTorr or 200 mTorr or any other entry in mTorr (depending on technician entry), when required for transducer calibration. The default vacuum reference shall be 200mTorr.

Hardware implementation of automatic system will include:

Item	Specifications	Suggested Equipment
Pressure Controller or Pressure controllers	Range: to cover pressure calibration for pressure transducers with ranges between 1 PSI to 3000 PSI System Measurement Uncertainty: equal to or better than 0.015% of pressure setting from 1 psi to 2000 psi; 0.02% of pressure setting above 2000 psi and below 1 psi for a calibration cycle of 1 year. See note for the accuracy explanation.	
Digital Multimeter	Accuracy: 4ppm Reading (Rdg) +0.05ppm Range (Rng)	Equivalent or better than: HP3458A Opt 002 This shall be supplied by NASA.
PC that controls the calibration system	Of sufficient capabilities to run Windows XP or Vista, control calibration process and provide reports	NA
20-Channel Multiplexer (data acquisition /switch unit)		Equivalent or better than: Agilent 34970A
Pressure intensifier (gas	To intensify the source	NA

booster)	supply of GN_2 to 3000 psi from the source supply of approximately 1,500 to 2,400 psi.	
Adjustable System DC Power supply(for units under test (UUT))	Full scale voltage: 0-50 VDC Full scale Current: 0-2 Amp Ripple and Noise (20Hz to 20MHz): 3mVpp / 0.5mVrms Single output	Equivalent or better than: HP 6633B
Programmable Resistance Decade Box	Accuracy : 0.01% RDG Range: 0-100K with a minimum of 1 ohm resolution	Equivalent or better than: IET PRS Series 200
Supporting components (automatic valves, tubing, hose, cables that interconnect all components)	All hoses used shall be in compliance with NASA Safety Manual, chapter 7. Each hose must consist of a seamless polytetrafluoroethylene (PTFE, eg., Teflon) inner tube reinforced with stainless steel wire construction of braid, spiral or combination wrap with fittings of 300-series stainless steel. They must be pressure tested to 1.1 times the maximum working pressure that they will encounter. A certificate for each hose should be supplied as part of the deliverable product. They must be individually tagged with a unique identification number that is traceable to the supporting documentation. Each hose should be tagged to indicate the certification date, the media tested (GN_2), the maximum working pressure, the manufacturer and part number.	NA

Note: The calculation of the accuracy should conform with the recommendations of the ISO Guide to the expression of Uncertainty in Measurement. The coverage factor should be k=2 for a normal distribution which corresponds to a coverage probability of approximately 95%. The accuracy should combine the effects of linearity, hysteresis, repeatability and stability throughout the operating temperature range.

2.2. Software

The software code must be an open architecture and should be not compiled to allow modifications by NASA personnel or their designees. The system shall allow future communication and expansion using the IEEE-488 bus so an IEEE-488 interface shall be supplied.

The Glenn Research Center shall be given the ability to modify the supplied software in the future without additional costs from the supplier. This shall be done using IEEE-488 bus communication.

The software should fully automate the process of calibration for 10 pressure transducers, concurrently. This includes but is not limited to: control precision pressure source, an environmental (thermal) chamber, and various laboratory instruments listed above with minimum manual interaction or operations. The measurement uncertainty of the process (including components from DMM, scanner, repeatability etc) should be calculated and reported automatically along with calibration points. The measurement uncertainty of the process should conform with the recommendations of the ISO Guide to the Expression of Uncertainty in Measurement (GUM). An Excel spreadsheet with the explanation of calculations for measurement uncertainties of the process should be provided in order to validate the system.

The system should allow the technician to set up the following UUT's parameters (pressure range, type of test, checklist, compensated temperature etc.), execute the software application to perform the calibration process and the technician should not have to interface with the system until all of the data is collected and the data reduction is complete. Authorization by the Cal tech for printing calibration reports should be prompted before printing. The software will allow the technician to enter and store the setup, ancillary data and test sequences for pressure and temperature. The vacuum pumps, the pressure controllers and environmental chambers will be then automatically activated by the technician entering the applicable software procedures. The software needs to allow the system to perform diagnostics to verify proper operation and isolate problems to major components and subassemblies.

The software will also automatically process the data using the pre-selected data reduction method, print copy of calibration results for each individual transducer, and store the report in a Microsoft Excel-compatible spreadsheet format (see Appendix 1 for the data required and Appendix 2 for the calibration results format). Also the software has to be able to compare and evaluate (pass or fail) to specifications.

The UUT (unit under test) specifications and the acceptable guardbanding that was determined to assure a customer risk of 2% will be entered by authorized personnel, only, in a unique checklist. This authorized person is the only one that could change the lists above. The pass /fail will be determined automatically by comparing the test result with the acceptable 2% guardbanding limits. If the authorized person did not populate the acceptable 2% guard band limits in a specific checklist, then the software should default the pass/ fail evaluation by comparing the test result with the UUT tolerance with an acceptable guardbanding limits calculated as described in the 2008 NCSL International Workshop and Symposium paper, “A Guard-Band Strategy for Managing False –Accept Risk” by Michael Dobbert, Agilent Technologies.

Each time the system is setup for calibration of units-under-test, the excitation voltage should be measured by the system DMM and that value should be used to decrease overall measurement uncertainty of the calibration process. The calibration process will *not* rely on the accuracy of the system power supply.

Each transducer has unique constants (sensitivity and output with zero pressure). Assuming the device is linear; errors of the transducer, unit(s) under test) are the nonlinearity and the hysteresis which define variation from the assumed linear output. Additional errors are those which result in changes of sensitivity and zero output with temperature, over-range of pressure, and pressure cycling. Zero output and sensitivity may also change with the application of a reference pressure to both sides of a differential pressure transducer. All those errors will be processed during the tests below.

There are four sets of tests: calibration, calibration with repeatability, evaluation and temperature. Each one comprised of a specific test sequence (see Appendix 1). Each test sequence should be selected by default but could be de-selectable by operator at the beginning of the calibration process. For the contents of each set of test for the calibration, evaluation and temperature, see Appendix 2. The “calibration with repeatability” test will consist of the following test sequences: exercise, and two or more calibration cycles that shall be run consecutively. The number of consecutive runs will be chosen by technician at the beginning of the test with two consecutive runs being the default. The time duration of each calibration cycle shall be stated. If two calibration cycles will be used, the repeatability will be calculating as

Repeatability: max (ABS (max (x_{1i}- x_{2i}), min ((x_{1i}- x_{2i}),) expressed in % FSO, where i= is the number of pressure point (ex. i=1 for the first pressure point taken, i=2 for the second data point… i=21 for the last data point taken in the run), 1 represent the first run and 2 represent the second run.

If more than two consecutive runs will be chosen the repeatability will be calculated as the maximum of the standard deviations as

Max (stddev($x_{1i,}$ $x_{2i,}$ $x_{3i.....,}$ x_{ni})) expressed in % FSO

The tests sequences that need to be performed are:

2.2.1. Pressure Calibration

The pressure to the transducer is taken in approximately 10 percent increments from zero to full scale and back to zero for a 21-steps calibration. No data is taken until stability is achieved. From this pressure calibration the nonlinearity, hysteresis, zero unbalance, and sensitivity of the transducer will be determined.

2.2.2. Exercise Program

In this program the transducers are exercised three times from zero to full scale pressure and back to zero. The full scale pressure and the zero pressure will be maintained for a minute. Data is taken at zero and at full scale with the scope to evaluate the calibration curve before and after cycling are compared for changes in zero unbalance and sensitivity. These changes indicate the repeatability of the transducer before and after exercise. The exercise repeatability is defined as the square root of the sum of the squares of the changes in sensitivity and zero unbalance for calibration taken before and after pressure cycling.

$$Rp_i = \{(Zero_{i\ after\ cycling} - Zero_{i\ before\ cycling})^2 + (S_{i\ after\ cycling} - S_{i\ before\ cycling})^2\}^{1/2} * 100 / span$$

2.2.3. Overpressure test

In this step of the program the transducers are overranged with the overrange pressure entered by the technician prior to the test. Data is taken during this step to compare zero unbalance, sensitivity and nonlinearity. The method of calculating overpressure is reported in the cal certificate as overpressure. Overpressure is the square root of the sum of the squares of the differences in Zero and sensitivity before and after subjecting the transducers to the manufacturer's specified overpressure limits. Overpressure is expressed in percent of full scale. Note: The maximum pressure used in overpressure test is 3000 PSI.

$$O_i = \{(Zero_{i\ after\ overpressure} - Zero_{I\ before\ overpressure})^2 + (S_{i\ after\ overpressure} - S_{i\ before\ overpressure})^2\}^{1/2} * 100 / span$$

2.2.4. Temperature program

This program sequentially changes transducer temperatures so that the calibrations at desired temperature are obtained. The temperature sequence is: the ambient temperature, the low temperature set by the technician, the ambient temperature, the high temperature set by the technician and ambient temperature (see Appendix 1). Between temperatures, a soak time is needed, in order to allow the stability of the new temperature. The soak time will be selectable by the technician, but the default is one (1) hour. For each temperature listed above, 21 pressure points will be taken in accordance with the description of Pressure Calibration (1.2.1). For each temperature listed a temperature sensitivity shift and a temperature zero shift is calculated. The temperature sensitivity shift is calculated as the difference between the sensitivity after exercise and sensitivity at each temperature. The temperature sensitivity shift is expressed as percent of full scale. The temperature zero shift is calculated as a difference between the zero after exercise and the zero after the temperature is applied. The temperature zero shift is expressed as percent of full scale.

The software needs to communicate with both existing environmental chambers. The existing environmental chambers are: Tenny Environmental Benchmaster model BTC and BTRC. The communications with these two chambers is achieved through an IEEE-488. The oven used shall be chosen by technician at the time of ancillary data entering. The temperature could be read with either the oven or with a Hydra Fluke 2625A Data acquisition unit through an IEEE-488. The read device needs to be chosen by the technician at the time of ancillary data entry, with the default being the Fluke Hydra.

2.2.5. Line test

This test is performed for differential pressure transducers only. Line pressure is the maximum pressure that can be applied to both ports of the differential pressure transducer without causing damage to the pressure transducer. During the line test the following sub-test are performed: line atmosphere, line pressure, line atmosphere, line vacuum (200 mTorr is applied to both ports of the pressure transducer). For each line sub-test the zero output is recorded as percentage of full scale.

2.2. 6. **R-cal run** (for Strain gage type transducers only and if load data is required)

The R-cal is a method by which the user can obtain an electrical signal from the transducer that simulates the effect of the known pressure. Values of R-cal resistors are generated from the automatic pressure calibration. These values are the resistance values which will produce 100%, 80% and 60% percent of the full scale output when connected between the positive input and the positive output corners of the bridge at zero pressure. When the R-cal section of the program is initiated, a variable resistor with the Programmable Resistance Decade Box is applied to the bridge at zero pressure and the value of the resistor is slewed until 60% FS of voltage output is reached. The same process is for 80% and 100% of FS output. Resistance shall be resolved and reported to one (1) ohm resolution.

2.2.7. E-check (for stain gauge only)

The output of the bridge when unbalanced by 50000 ohms applied between + excitation and + output, divided by the excitation voltage .Units are mV/V.

2.2.8. E-standard (for strain gauge only)

The output of the bridge when unbalanced by 50000 ohms applied between excitation + output, divided by the excitation voltage, corrected for residual zero. Units are expressed in mV/V.

2.2.9. No-load data

Output of the strain gauge into high impedance.

2.2.10. Load data

Output of the strain gauge into a 1750 ohm-load resistor.

3. SAFETY

The system is required to contain sufficient safety features to insure safe operation. All components and the system, itself, shall be delivered certified to safely work at intended operating pressure range. All hoses used shall be in compliance with NASA Safety Manual, chapter 7. Each hose must consist of a seamless polytetrafluoroethylene (PTFE, eg., Teflon) inner tube reinforced with stainless steel wire construction of braid, spiral or combination wrap with fittings of 300-series stainless steel. They must be pressure tested to 1.1 times the maximum working pressure that they will encounter. A certificate for each hose should be supplied as part of the deliverable. They must be individually tagged with a unique identification number that is traceable to the supporting documentation. Each hose should be tagged to indicate the certification date, the media tested (GN_2), the maximum working pressure, the manufacturer and part number.

4. DEFINITION OF TERMS

All these terms are taken from the ISA-37.1-1975 (R1982) "Electrical Transducer Nomenclature and Terminology"

Best Straight Line A line midway between the two parallel straight lines closest together and enclosing all output vs. Measurand values on the Calibration Curve. (ISA-S37.1-1975 (R 1982), page 15)

Calibration Cycle the application of known values of Measurand, and recording of corresponding Output readings, over the full (or specific portion of) range of the transducer in an ascending and descending direction. (ISA-S37.1-1975 (R 1982), page 15)

End points: The outputs at the specified upper and lower limits of the range. (ISA-S37.1-1975 (R 1982), page 16)

End point line: The straight line between the end points. (ISA-S37.1-1975 (R 1982), page 17)

Full Scale output The algebraic difference between the end points

Z_i residual zero -The output signal when no pressure is applied to the transducer. The residual zero is express in percent of full scale.

S_i Sensitivity- Is the ratio of the change in transducer output to a change in the value of the measured. The units are mV/V.

H_i **Hysteresis** The maximum difference in Output at any measurand value within the specified range ,when the value is approached first with increasing and then with decreasing measurand. Hysteresis is expressed in percent of full scale output, during any one calibration cycle. (ISA-S37.1-1975 (R 1982), page 18)

Least-square line the straight line for which the sum of the squares of the residuals (deviations) is minimized.

Linearity The closeness of a calibration curve to a specified straight line. Linearity is expressed as the maximum deviation of any one calibration cycle. It is expressed as +/- percent of full scale output (ISA-S37.1-1975 (R 1982), page 19)

Linearity ,end point : Linearity referred to the End point line. ISA-S37.1-1975 (R 1982), page 19)

Linearity ,independent: Linearity referred to the Best Straight Line. ISA-S37.1-1975 (R 1982), page 19)

Over pressure The maximum pressure that can be applied to a pressure transducer without causing damage to the transducer.

Line Pressure The maximum pressure that can be applied to both ports of the differential pressure transducer without causing damage to the pressure transducer.

5. DATA REDUCTION

There are several data reductions types used at NASA Glenn Research' calibration lab: Terminal point line, Best fit straight line (independent linearity), Zero-based linearity.

LINEARITY, TERMINAL -BASED (a.k.a End point method) ANSI/ISA -51.1-1979 (R1993) "Process Instrumentation Terminology" standard (pag.39, pag.64)

Linearity terminal based is the maximum deviation of the calibration curve from a straight line coinciding with the calibration curve at the upper and lower range-values.

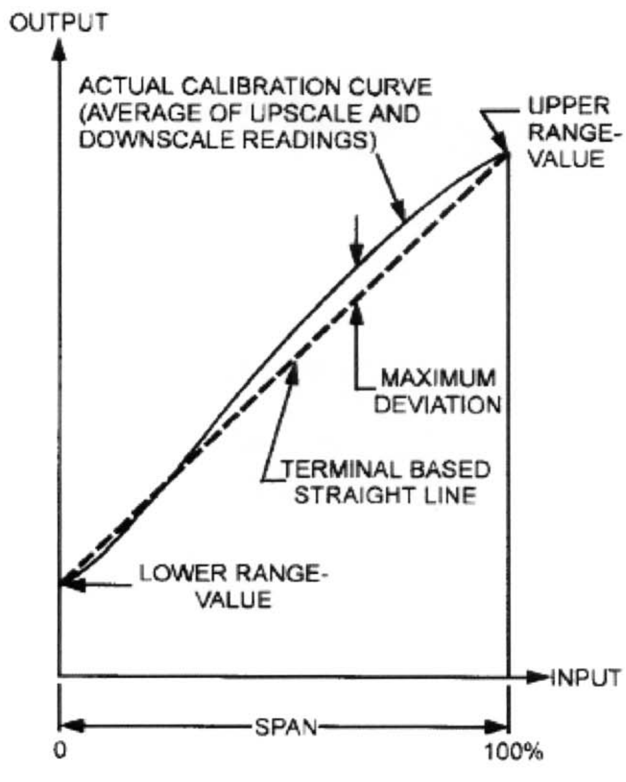

Figure 20 — Terminal-based linearity

LINEARITY ,INDEPENDENT (a.k.a BEST FIT STRAIGHT LINEARITY) ANSI/ISA -51.1-1979 (R1993) "Process Instrumentation Terminology" standard(pag.39, pag.64)

Linearity independent is the maximum deviation of the calibration curve from a straight line so positioned as to minimize the maximum deviation

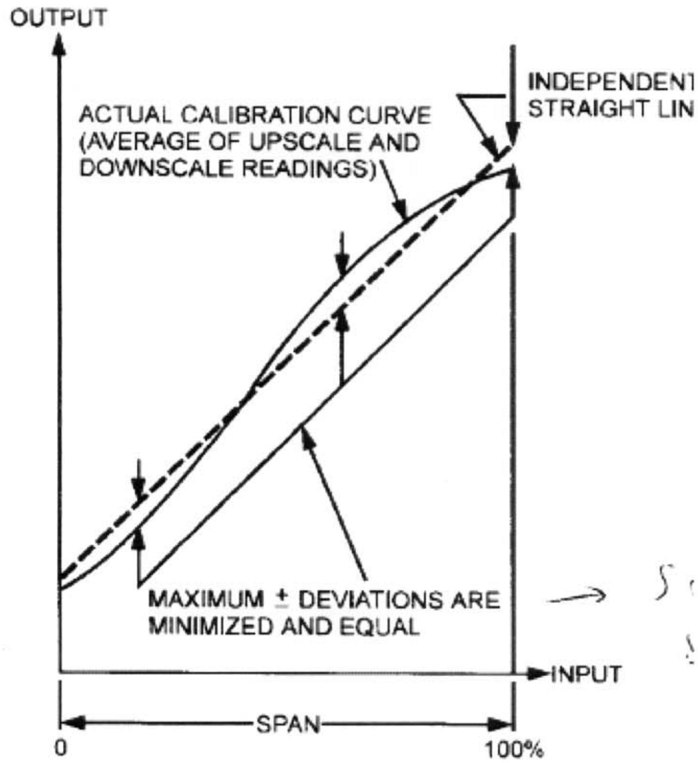

Figure 19 — Independent linearity

LINEARITY , ZERO-BASED(a.k.a BEST FIT STRAIGHT LINEARITY THROUGH ZERO)
ANSI/ISA -51.1-1979 (R1993) "Process Instrumentation Terminology" standard (pag.39, pag.64)

Linearity zero-based is the maximum deviation of the calibration curve from a straight line so position as to coincide with the calibration curve at the low range-value and to minimize the maximum deviation.

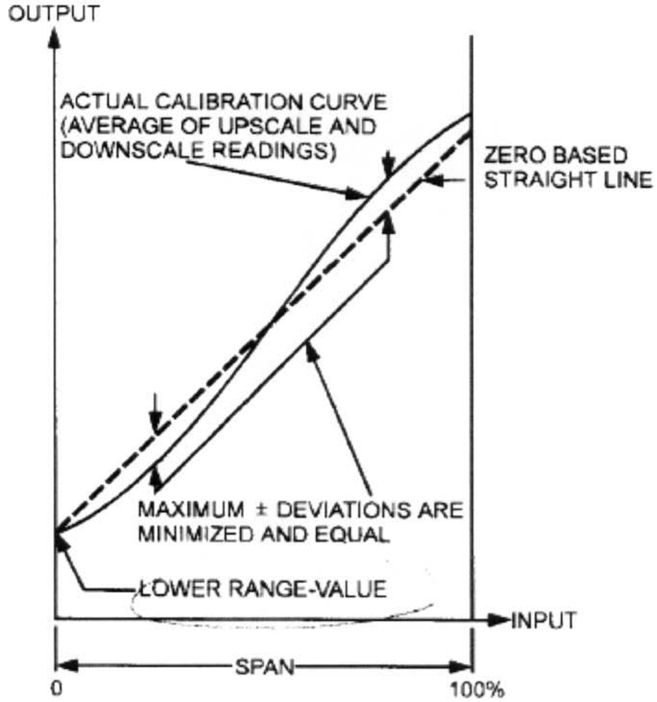

Figure 21 — Zero-based linearity

ᴈe zone, live.

APPENDIX 1. Automated Transducer Calibration Sequence

Automated Transducer Calibration Sequence												
Absolute				Gauge				Differential				
Cal	Cal with repeatability	Eval	Temp	Cal	Cal with repeatability	Eval	Temp	Cal	Cal with repeatability	Eval	Temp	
		X	X			X	X			X	X	21 point #1 initial data
		X	X			X	X			X	X	Exercise (zero to full scale 3 times)
		X	X			X	X			X	X	21 point #2 exercise data
		X	X			X	X			X	X	Overpressure to rated pressure
		X	X			X	X			X	X	21 point # 3 Overpressure data
			X				X				X	Low temperature soak
			X				X				X	21 point #4 low temperature data
			X				X				X	Ambient temperature soak
			X				X				X	21 point #5 ambient temperature data
			X				X				X	High Temperature soak
			X				X				X	21 point #6 high temperature data
			X				X				X	Ambient Temperature soak
			X				X				X	21 point #7 ambient temperature data
										X	X	Line atmosphere. Read zero
										X	X	Line Pressure . Read zero
										X	X	Line atmosphere. Read zero
										X	X	Line Vacuum. Read zero
						X	X					Vacuum
						X	X			X	X	Return to atmosphere
X	X	X	X	X	X	X	X	X	X	X	X	Exercise (zero to full scale 3 times)
X	X	X	X	X	X	X	X	X	X	X	X	21 point #8 final data (first run)
X	X	X	X	X	X	X	X	X	X	X	X	Rcal first run (if load data required)
X	X	X	X	X	X	X	X	X	X	X	X	E-check first run (if strain gauge)
	X				X				X			21 point #9 final data (second run)
	X				X				X			Rcal second run (if load data required)
	X				X				X			E-check second run (if strain gauge)
	.				.				.			.
	.				.				.			.
	.				.				.			.
	X				X				X			21 point #8+n final data (n th run)
	X				X				X			Rcal nth run (if load data required)
	X				X				X			E-check nth run (if strain gauge)

21 point data is the transducer's output at the following pressures:
Zero, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100% full scale increasing pressure and 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, and zero decreasing pressure.
Load data is with a 1750 ohm load on the transducer's output.
R-cal and E-check resistance is applied between + excitation and + output of the strain gauge bridge
Temperatures soak (soak time starting when environmental chamber temperature measures within 1 deg F of set point).

Appendix 2, Sample Datasheet Example

NASA GRC EQUIPMENT CHECKLIST

(Primary Pressure Laboratory - Transducer)

ECN	Check List	Procedure		Work Order	Test Result
Manufacturer	MP469CLS	PROC-MP-0002		464968	PASS
Manufacturer	Model	Serial Number		Type	Range
Setra	239	351908		Differential	2.5"H2O
Test Excitation	Reference Pressure	Test Temp	Humidity	Technician	Calibration Date
24 VDC	NA	72 °F	41%	RJH24	3-Jun-04

Data Reduction Method:	Setra Best Fit Straight Line	Initial and Final Data

Remarks:
Manufacturer Specifications.
Reference Specifications on file.
Output 0-5 VDC. Unidirectional Range
For stated accuracy unit should be zeroed before use.
MUA calculated due to a TUR=0.63
Standard uncertainty that combined uncertainty of pressure standard and uncertainty of voltmeter is ±0.006 inch wc

NO LOAD DATA

Pressure %FS	Output		Test Result	Tol.	MUA	Guard band to managed False-Accept Risk		
0	0.0000 V	Sensitivity	NA	NA			NA	NA
20	1.0012 V							
40	2.0010 V	Residual Zero	0.035 %FS	NA			NA	NA
60	2.9983 V							
80	3.9975 V	Hysteresis	0.037 %FS	±0.10 %FS			PASS	PASS
100	4.9965 V							
80	3.9976 V	Linearity	0.030 %FS	±0.10 %FS			PASS	PASS
60	2.9972 V							
40	2.0018 V	Accuracy:	0.048 %FS	0.14 %FS			PASS	PASS
20	1.0006 V			(RSS Linearity & Hysteresis)				
0	0.0019 V					mV/V @50KΩ		

Slope (mV/V)x(psi)	E Standard	E Check
NA	NA	NA

Approved	Date	Revision Level	Page 1 of 1
MF	8-Sep-04	Basic	